A COMPARATIVE NET ENERGY ANALYSIS OF FUEL OIL PRODUCTION FROM CRUDE OIL AND OIL SHALE

Alton J. Frabetti, Jr.; James D. Westfield; Morton Gorden

DEVELOPMENT SCIENCES INC., East Sandwich, Massachusetts

Public Law 93-577

As the issues surrounding energy policy formation proliferate, attention has been called to the concept of "net energy" as noted in PL 93-577 (Federal Non-nuclear Energy Research and Development Act of 1974). The relevant section of the Act is as follows:

> "The potential for production of net energy by the proposed technology at the stage of commercial application shall be analyzed and considered in evaluating proposals."

The concern for net energy, basically the amount of energy that it takes to deliver energy in usable form, has been voiced because, as we run short of petroleum and as we seek national self-sufficiency, the new technologies that we employ to extract and transform energy require an energy penalty themselves. Thus, as we climb the curve of energy output, the diminishing returns will push us into a more and more rapid rate of resource depletion and cost penalty, perhaps forcing a re-evaluation of consumer demand schedules. The phrase "net energy" was developed because new forms of energy may cost more energy to get than they pay back.

Methodology

This paper is based on a study sponsored by the U. S. Department of the Interior (Reference 1). Data for other fuel supply pathways also are presented in Reference 1. The goal of this study was to calculate the true energy costs to society associated with the delivery of a given amount of usable energy (1000 Btu) by various energy supply systems. To be included as part of the energy costs were not only the direct process energy requirements but also the indirect costs associated with the production of the process energy itself and with the production of the plant operating supplies and (amortized) capital equipment.

Existing methods of energy analysis were reviewed. These fell into three broad categories: vertical analysis, pure Input/Output energy analysis, and the approach known under the general name of eco-energetics, developed by H. Odum. Vertical analysis -- detailed tracing of each equipment input back to its resource form -- was considered to be too tedious. Pure Input/Output analysis, using statistical data associated with the current United States economy, could not per se reflect the effects of the newer or future energy technologies. The eco-energetics approach was not utilized because the concepts and procedures are not sufficiently developed at the present time.

It finally was decided to use a combination of process analysis and Input/Output theory, the first time that this hybrid approach has been taken. Process analysis was used to treat the direct process energy contributions, and Input/Output coefficients were utilized to treat the indirect capital energies.

The various steps associated with each energy delivery pathway were analyzed in a modular fashion, converting each of the external direct and indirect energy inputs as described above (Figure 1). These then were combined, with the appropriate transportation steps included, to give complete energy delivery pathways (Figure 2). Provisions were included in each pathway to transport raw materials and water to the plant site, when necessary, and also to bring all products and by-products to central distribution points. By-product energy values were generally determined but not added to the resource energy output. The primary exception to this was in the oil pathway, where all refinery products were included as part of the resource yield. Equipment and operating energies associated with final product distribution (e.g., an oil delivery truck) were not included.

The dramatic effects that the many decisions associated with the construction of each energy pathway can have on the results should be noted at this point. These variations fall into three major categories: deposit-related, process-related, and assumption-related (Figure 3). In the case of the deposit-related variations, the deposit quality can strongly affect the resulting in situ resource consumption and energy subsidy. Similarly, the targeted extent of resource recovery and the location of the various plants along the energy pathway can significantly affect the results.

Pathway for Fuel Oil from Crude Oil

The data for the fuel oil from crude pathway were drawn from United States national industry totals for the year 1972 in order to establish volumes, operating costs, and current investments in as comprehensive a manner as possible. References 2 - 4 were the primary data sources. At the early stages of the supply pathways, oil and gas production are highly associated. For example, about 22 percent (1972 basis) of the energy from oil wells is in the form of gas. Similarly, in every 1000 Btu of refinery product, there are 126 Btu of liquids from natural gas plants. These effects were taken into account and corrected for when calculating the resource flows and external energy subsidies associated with R&D, extraction, etc.

The data for the fuel oil from crude pathway are summarized in Table 1. The first column traces the crude from its in situ state to its final energy form normalized to 1000 Btu output. The diminution of resource in a step can be due to true loss (e.g., by evaporation or spillage) or to actual internal consumption of the resource within the step. The 2954.4 Btu of initial in-ground crude resource also includes the crude left behind in the ground (about 68% of the original deposit for primary and secondary recovery). The liquid gas plant products (126.3 Btu) are added to the oil resource flow. The resource loss of about 70 Btu in the refining step represents primarily internal consumption of oil in the various process units and auxiliary units.

The components of the external energy subsidy are displayed in the next two columns for each step in the pathway, again all normalized to support 1000 Btu of fuel output. External energy is (somewhat arbitrarily) defined as all energy delivered to the plant from outside the plant boundaries. The energy subsidy is divided into operating and capital components. The operating energy component includes direct process energy and indirect energy embodied in operating supplies and maintenance. Direct electricity use is converted at a rate of 11,405 Btu/kwh. Land reclamation energies also are included as part of the operating energies. The capital component includes the amortized capital equipment and plant construction-related energies.

The I/O energy coefficients for estimating energy implicit in material and equipment, expressed as Btu/$, were taken from the 1967 data in Reference 4 with suitable correction factors applied for inflation, U. S. energy intensity (i.e., coal versus crude), etc. The coefficients all were normalized to 1974 dollars. Typical corrected coefficient values ranged from about 40,000 Btu/$ for general construction activity to about 60,000 Btu/$ for major items of chemical plant equipment. The catalysts and chemicals category, in particular, had a very high energy coefficient of about 170,000 Btu/$. For the purposes of evaluating capital energies from these I/O energy coefficients, the plant capital cost was typically disaggregated into 5 - 10 subcategories. In Reference 1, the indirect capital and material-related energies are further disaggregated into their three basic components -- Btu from coal, oil plus gas, and hydro plus nuclear.

The fuel oil portion of the refinery product slate is about 6.11 percent by volume (1972 basis) but consumes only about 3.4 percent of the total refinery operating and capital energies for its production (Reference 1). The external operating energy subsidy for fuel oil production in the refinery is the largest subsidy in Tabel 1 (35.58 Btu). About 80 percent of this purchased energy is natural gas, and the remainder is primarily electricity. Another significant external subsidy is the 6.75 Btu associated with well drilling and with the well capital equipment.

In summary, 2954.4 Btu of reserve (crude) and 48.68 Btu of external energy are utilized to produce 1000 Btu of fuel oil. The tertiary oil recovery pathway also was examined in Reference 1. For this pathway, 117.32 Btu of external subsidy are consumed per 1000 Btu of fuel oil output, due primarily to the high chemicals consumption associated with the tertiary recovery operation.

Pathway for Fuel Oil from Oil Shale

This analysis is based primarily on an economic evaluation of shale oil production by the U. S. Department of the Interior utilizing the so-called gas combustion retort process (Reference 6). The hypothetical oil shale processing complex is located in Colorado and consists of three mines, three retorting plants, and a refinery to produce a semi-refined oil at a rate of 100,000 B/D.

The average oil content of the shale rock is 30 gallons/ton. The mines are underground mines with mining by the conventional room and pillar technique. About 44 T/D of explosives are required. The electrical power for the mine and process plants is generated within the mine/plant complex.

The crude shale oil from the retorts flows by pipeline to the refinery, a distance of about 40 miles. The excess low-Btu gas from the retorts also is piped to the refinery for use as process fuel and for power generation. Part of the spent shale is slurried and pumped back into the mines, and the remainder is deposited in a canyon.

In the refinery, the crude is heated and charged to a distillation column where it is separated into overhead and bottoms fractions (about 50 percent overhead). The overhead fraction is depropanized to yield distillate at a rate of 52,345 barrels per calendar day.

The bottoms fraction from the distillation column is fed to delayed coking units. The distillate product from the cokers is cooled, depropanized, and charged to hydrogenation along with the crude distillation tower overhead fraction. The coke from the drums, 1710 tons per calendar day, is stored for sale. The hydrocrackers produce a product containing about 60 volume percent material in the gasoline boiling range. The uncondensed gas is used for plant fuel, and the liquid hydrogenated product (100,000 barrels per calendar day) is pumped to storage.

The gas streams from the hydrogenation, delayed coking, and distillation contain sulfur and nitrogen, in the form of hydrogen sulfide and ammonia, available for recovery. The hydrogen sulfide is ultimately processed in a Claus unit to yield

85.5 tons per calendar day of sulfur. The ammonia is recovered in liquid form to yield 275.5 tons per calendar day.

A portion of the above gas streams, after hydrogen sulfide and ammonia removal, is passed to a hydrogen plant to supply hydrogen for hydrogenation, and the remainder is utilized for process fuel and on-site power generation, supplemented by 3.61 MM SCF per calendar day of purchased natural gas.

The resource path for the oil shale system is shown in the first column of Table 2. By analogy with underground coal mining, 43 percent of the resource was assumed to be left in the ground (e.g., as pillars in the mine). The heat content of the by-products (coke, sulfur, and ammonia) was not included as part of the resource output, although it was equivalent to about 8 percent of the product oil energy.

The external subsidies are shown in the next two columns of Table 2. Because the mines and plants are designed as a single, integrated complex, it was not possible to separate the subsidies. For example, power used in the mine is generated at the refinery utilizing both excess low-Btu retort gas and purchased natural gas. This excess retort gas represents an internal resource consumption.

The external operating subsidy of 32.9 Btu is shown in detail in Table 3. The subsidies are seen to be fairly evenly distributed among such items as purchased natural gas, catalyst and chemicals, and explosives. The oil transport step assumed a 500-mile pipeline, of which 300 miles was existing and 200 miles represented new construction.

Comparison of Crude Oil and Oil Shale Results

At first glance, the oil shale external subsidy of 39.1 Btu per 1000 versus the crude oil subsidy of 48.7 would appear to indicate that oil from oil shale requires less external energy than oil from crude oil. However, the shale oil pathway was designed, in effect, to minimize the external subsidies, but the crude pathway was not. For example, about 180,000 kw of power are generated within the shale mine-plant complex. Converted at 11,405 Btu/kwh, this corresponds to an additional subsidy of about 80 Btu per 1000 Btu output if it were purchased from outside the plant. Of course, at least a part of the current natural gas subsidy of 6.2 Btu per 1000 Btu would be eliminated. The resulting total external subsidy for the external power purchase pathway would be on the order of 113 - 119 Btu per 1000 Btu, which is seen to be significantly greater than that for crude oil.

It should be noted that all of the above subsidies indirectly reflect the relatively low "energy to produce energy" of the United States economy over the last decade. Stated differently, the steel used, for example, in the shale processing equipment was produced using easy-to-obtain energy. As some of the above newer, more energy-intensive energy supply systems permeate the economy, these higher order energy effects will start to increase all of the external subsidies and resource consumptions.

REFERENCES

1. "A Study to Develop Energy Estimates of Merit for Selected Fuel Technologies," report to the U. S. Department of the Interior, Office of Research and Development, Contract No. 14-01-001-2141, September 23, 1975.

2. Bureau of Mines, U. S. Department of the Interior, Washington, D. C., "Mineral Industry Surveys: Crude Petroleum, Petroleum Products and Natural-Gas-Liquids: 1972," prepared December 21, 1973.

3. American Gas Association, Arlington, Virginia, "1973 Gas Facts, A Statistical Record of the Gas Utility Industry."

4. American Petroleum Institute, Washington, D. C., "Petroleum Facts and Figures, 1971 Edition;" "Annual Statistical Review, U. S. Petroleum Industry Statistics, 1956 - 1972;" "Joint Association Survey of the U. S. Oil and Gas Producing Industry, Section I - Drilling Costs, Section II - Expenditures for Exploration, Development, and Production," February 1975.

5. Herendeen, R. L.; Bullard, C. W., III; "Energy Cost of Commerce Goods, 1963 and 1967," CAC Document No. 140, Center for Advanced Computation, University of Illinois at Urbana-Champaign, November 1974.

6. Report No. 75-4, "Oil Shale - 1974, An Economic Evaluation Using 30 Gallon Shale and Producing 100,000 Barrels per Calendar Day of Shale Oil," Process Evaluation Group, Bureau of Mines, Morgantown, West Virginia, September 1974.

Table 1

SUMMARY - FUEL OIL PRODUCTION

Basis: 1,000 Btu Output

Pathway Step	Resource Remaining (Btu)	Energy Subsidy (Btu)		
		Operating	Capital	Total
In ground	2954.4 (start)	-	-	-
Research & Exploration	-	1.06	-	1.06
Production	945.4	2.58	6.75	9.33
Gathering	945.1	0.01	0.13	0.14
Add Natural Gas Plant Prod.	126.3	0.02	0.08	0.10
Available	1071.4			
Crude Pipeline	1070.8	0.06	0.54	0.60
Refinery Input	1070.5			
Refinery Output	1000.3	35.58	1.31	36.89
Product Pipeline	1000.0	0.05	0.51	0.56
TOTAL		39.36	9.32	48.68

Table 2

SUMMARY - OIL SHALE

Basis: 1,000 Btu Output

Pathway Step	Resource Remaining (Btu)	Energy Subsidy (Btu) Operating	Capital	Total
	2614.5* (start)	-	-	-
R & D	2614.5	3.6	-	3.6
Mine	1490.3***	(**)	(**)	(**)
Plant Complex	1000.0	23.5	6.0	29.5
Transport	1000.0	5.8	0.2	6.0
TOTAL		32.9	6.2	39.1

* In ground

** Included as part of plant complex

*** Resource at mine mouth

Table 3 OIL SHALE OPERATING SUBSIDIES

	SUBSIDY (BTU)
R&D; EXPLORATION	3.6
NATURAL GAS	6.2
CATALYST AND CHEMICALS	5.9
MAINTENANCE	2.4
GENERAL SUPPLIES	2.0
EXPLOSIVES	3.4
BY-PRODUCT COKE	(73.7)
BY-PRODUCT SULFUR AND AMMONIA	(6.5)
TRANSPORT (BY-PRODUCTS)	3.5
TRANSPORT (OIL)	5.8
LAND RECLAMATION	0.1
	32.9

Figure 1

RESOURCE AND ENERGY FLOWS FOR A TYPICAL STEP

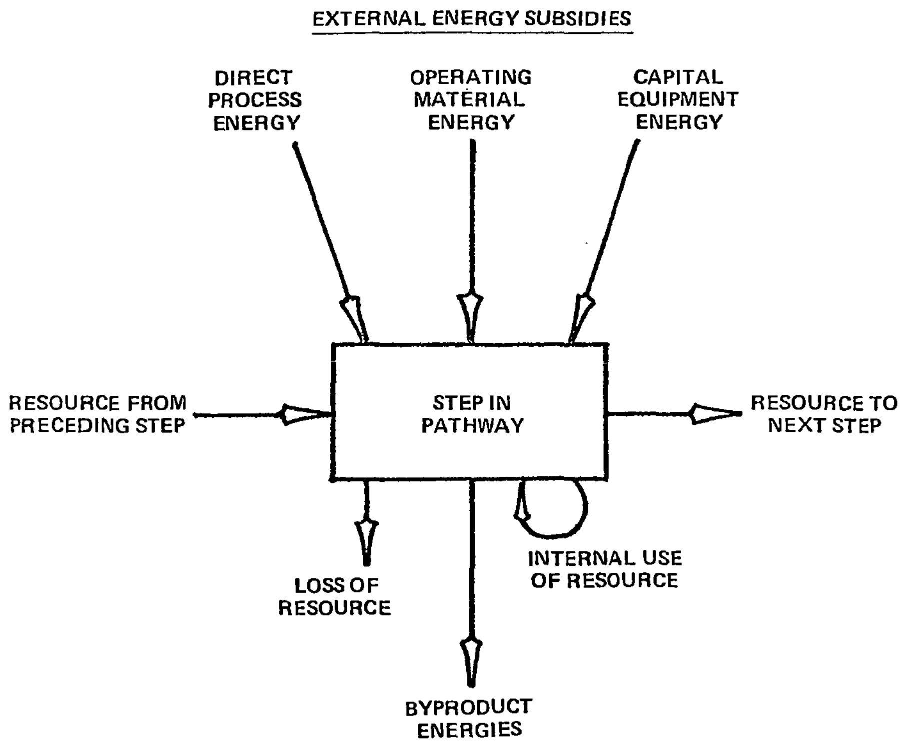

Figure 2 - ENERGY SUPPLY PATHWAY

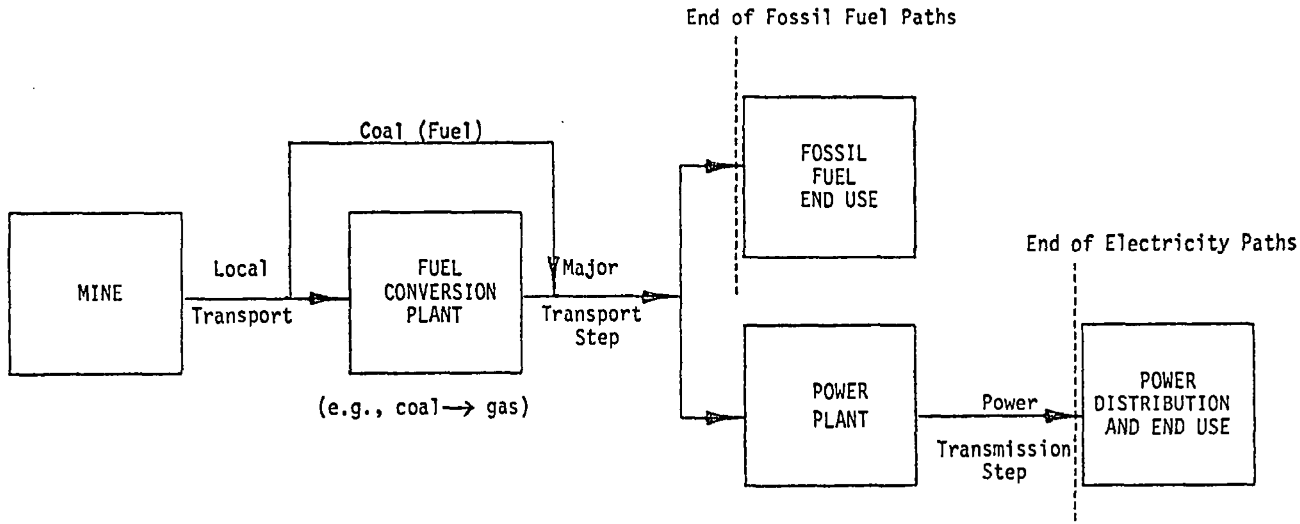

Figure 3

PATHWAY VARIATIONS

Deposit-Related Variations

Location of Deposit

Depth of Deposit

Thickness of Seam

Quality of Deposit

(Oil Content of Shale)

(Intensity of Solar Radiation)

Process-Related Variations

Extent of Recovery of Resource

State of Development of Technology

(Primary Vs. Tertiary Oil Recovery)

(Room and Pillar vs. Longwall Mining)

(Lurgi vs. Hygas for Coal Gasification)

(Surface Retorting vs. Modified In Situ for Oil Shale)

(Gas Centrifuge vs. Gaseous Diffusion for Nuclear)

Pathway Assumption-Related Variations

Location: Mine/Conversion Plant/Power Plant/Ultimate Use

Transportation: Raw Materials/Water/Products/By-products

New vs. Existing Transportation Facilities: Rail/Pipeline